Dark Matter Searches at CMS

TeV Particle Astrophysics 2021

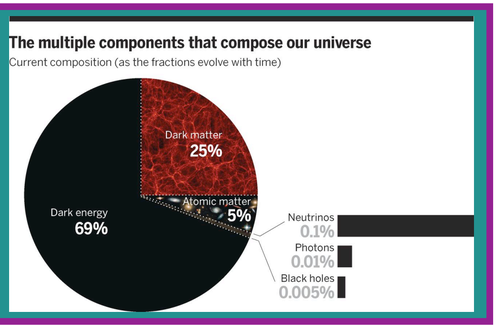
Deepak Kumar,
On behalf of CMS Collaboration

Indian Institute of Science, Bangalore, India

29th October 2021

Dark Matter and detection channels

- Existence of dark matter (DM) know from astrophysics and cosmos.
- Not observed directly.
- It rarely interact with ordinary matter via electro-magnetic interaction(WIMPs)
- From Cosmology, Universe contains 25% dark matter



1. Direct detection

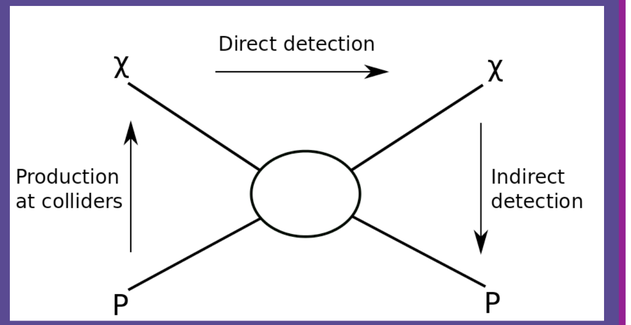
- DM interacts with ordinary matters such as nucleons.

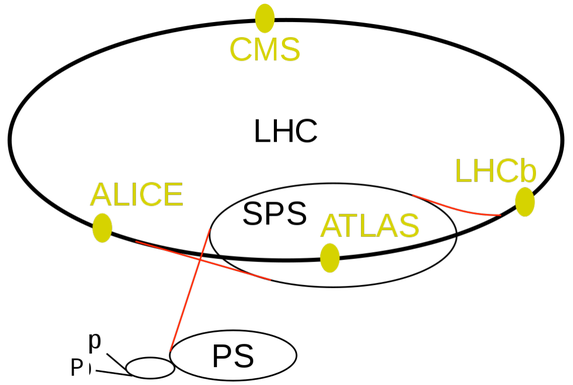
2. Indirect detection.

- DM self-annihilate or decay in outer space.

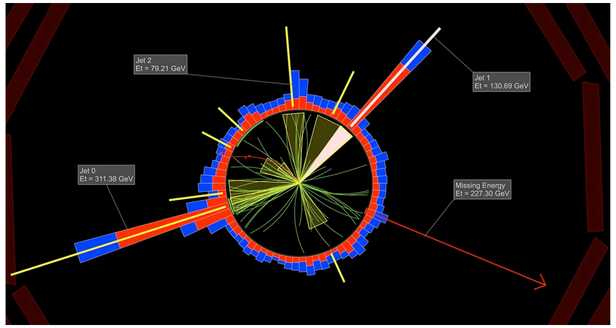
3. Particle colliders.

- Produce DM particles in a laboratory.





If DM can be produced at hadron colliders, then Large Hadron Collider (LHC) is the best laboratory to detect.

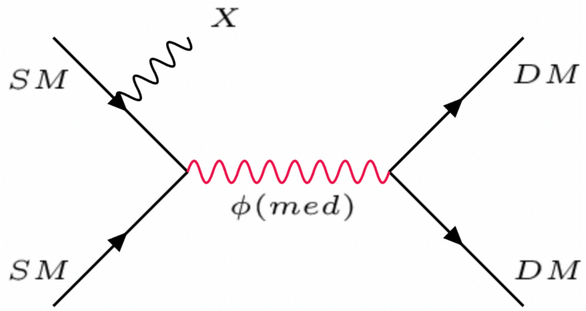


Dark matter detection at LHC

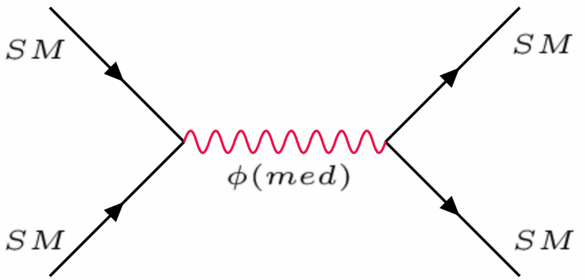
- mono-X search:
  - Standard model particle recoil against missing energy.
  - Tag from radiation or associated production
  - Expect signal in the tail of missing energy distribution over the standard model background.

- Resonance search:
  - DM decays to standard model particle.
  - Expect signal peak in invariant mass of two visible final sate particle above the standard model background.

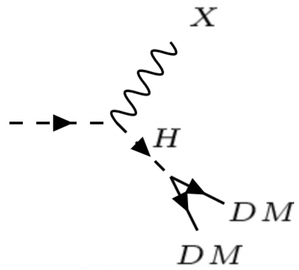
- Higgs portal:
  - Higgs decays to DM candidates.



mono-X search



Resonance search



Higgs portal

Outline

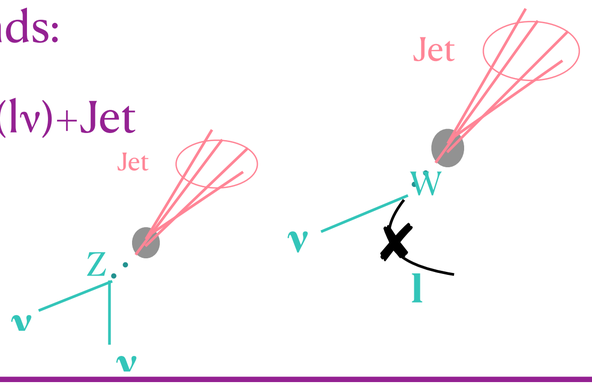
- **Analyses for main talk:**
  - mono-J/V search : EXO-20-004(arXiv:2107.13021)
  - mono-Z search : EXO-19-003 (Eur. Phys. J. C 81 (2021) 13)
  - mono-Higgs : EXO-18-011(JHEP 03 (2020) 025)
  - Dilepton resonance search : EXO-19-019(JHEP 07 (2021) 208)
  - Dijet resonance search : EXO-19-012(JHEP 05 (2020) 033)

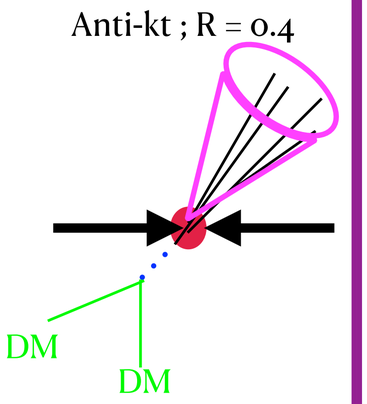
- **Full list of analyses are available here:**
  - **Public results**

mono-Jet/V search

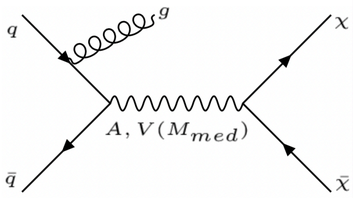
- Detector signature: jet+p_T^{miss}
- Two categories based on **jet nature**
  - Mono-J and mono-V
- Common selection:
  - p_T^{miss} > 250 GeV
  - No leptons, photon

- Major backgrounds:
  - Z(νν)+Jets, W(lν)+Jet

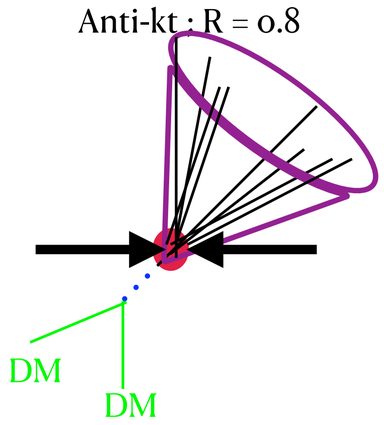




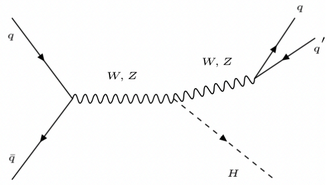
mono-J:
ak4 pT >100



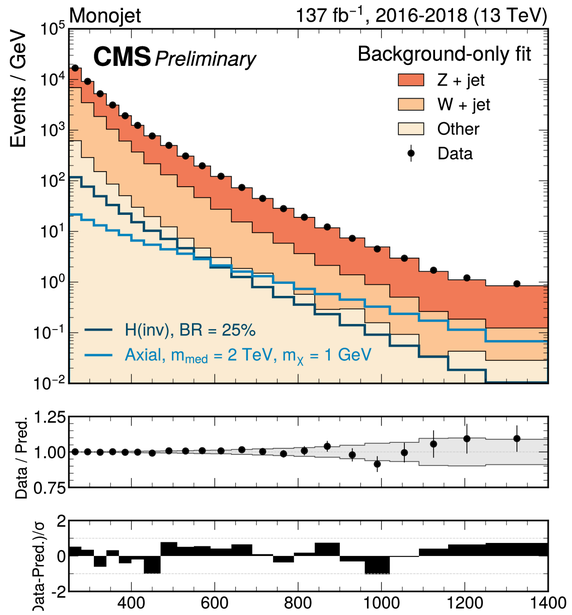
Feynman diagram

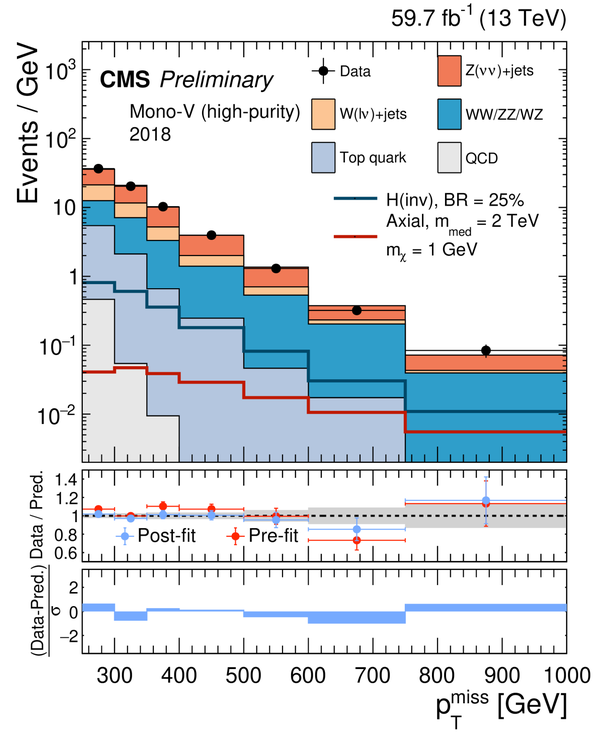


mono-V:
fatjet pT >200
mass window [65-120]



Feynman diagram

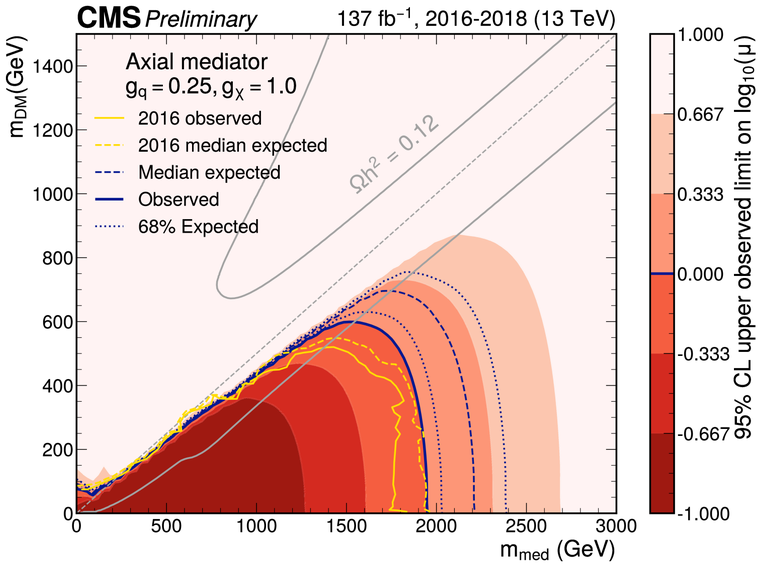




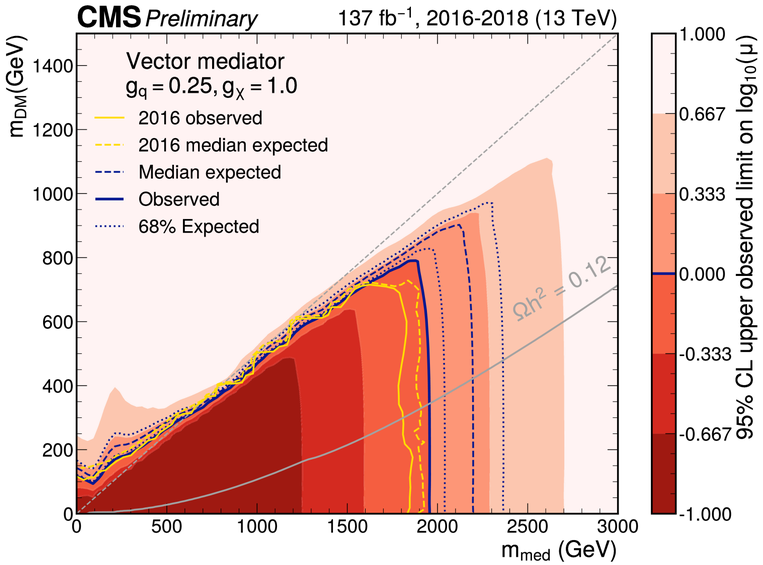
No excess of event observed with respect to SM background expectations.

mono-Jet/V search

Axial vector mediator

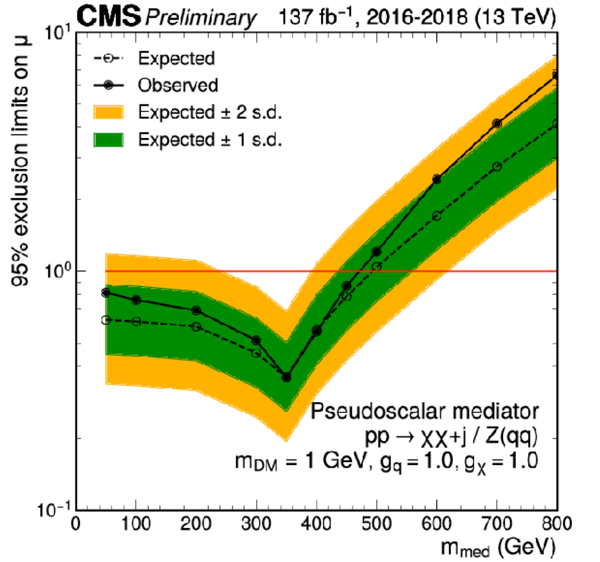


Vector mediator

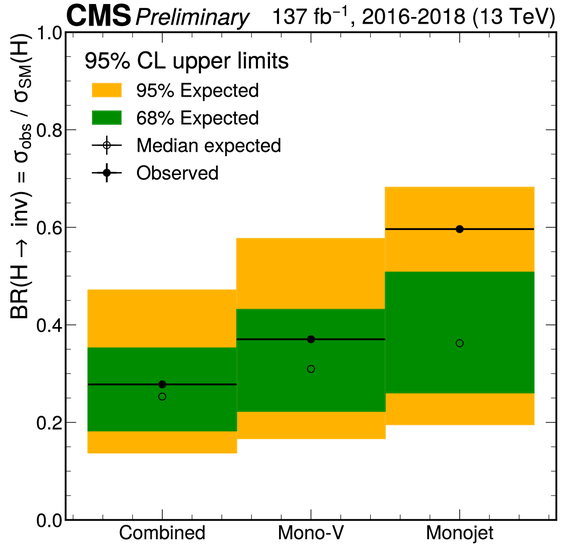


Values of the mediator mass are excluded up to 1.95 TeV

Pseudo scalar mediator



Values less than 470 GeV are exclude



BR(H→ inv) < 27.8 % (25.5% exp)

mono-Z(ll) Search

Signature: Z(ll)+MET

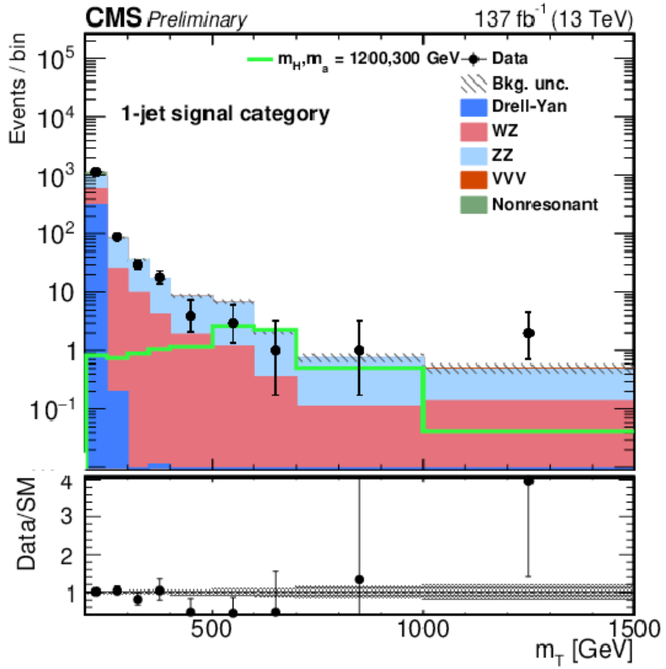
Model for interpretations:
- Simplified model
- 2HDM+a

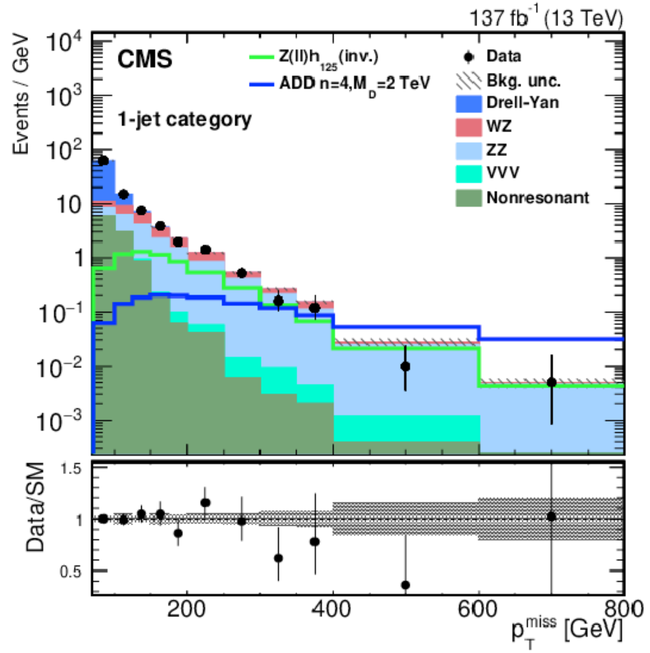
p_T^{miss} for simplified, m_T for 2HDM+a model

$$m_T = \sqrt{2 p_T^Z p_T^{miss} (1 - \cos(\Delta\phi_{\ell\ell - \vec{p}_T^{miss}}))},$$

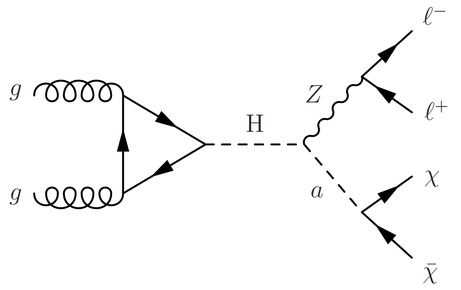
Basic selection:
- $p_{T(l1)} > 25$ GeV, $p_{T(l2)} > 20$ GeV
- $|m_{ll} - m_Z| < 15$ GeV
- MET > 100 GeV

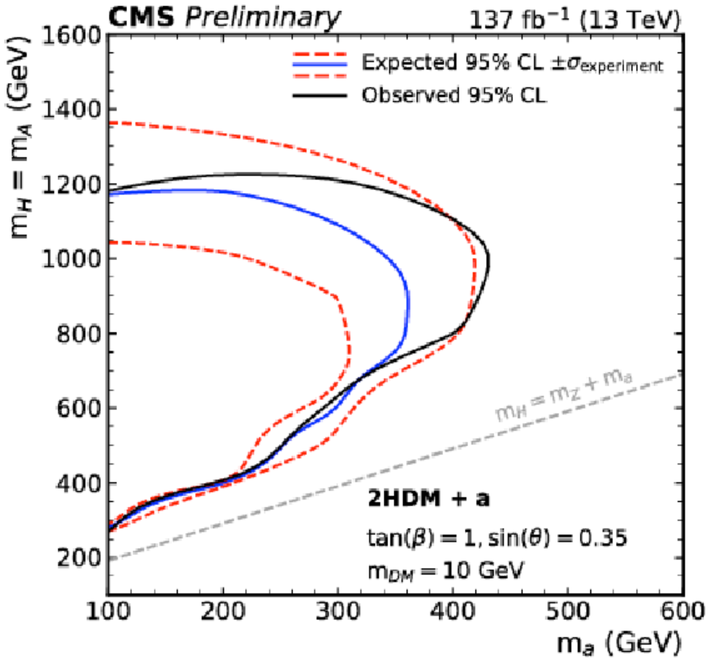
Backgrounds:
- Drell-Yan, WZ, ZZ, VVV
- Dedicated Control regions to model the background





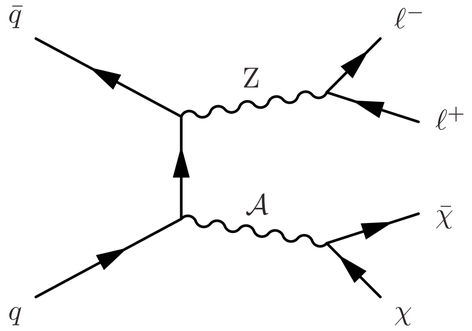
2HDM+a model interpretation





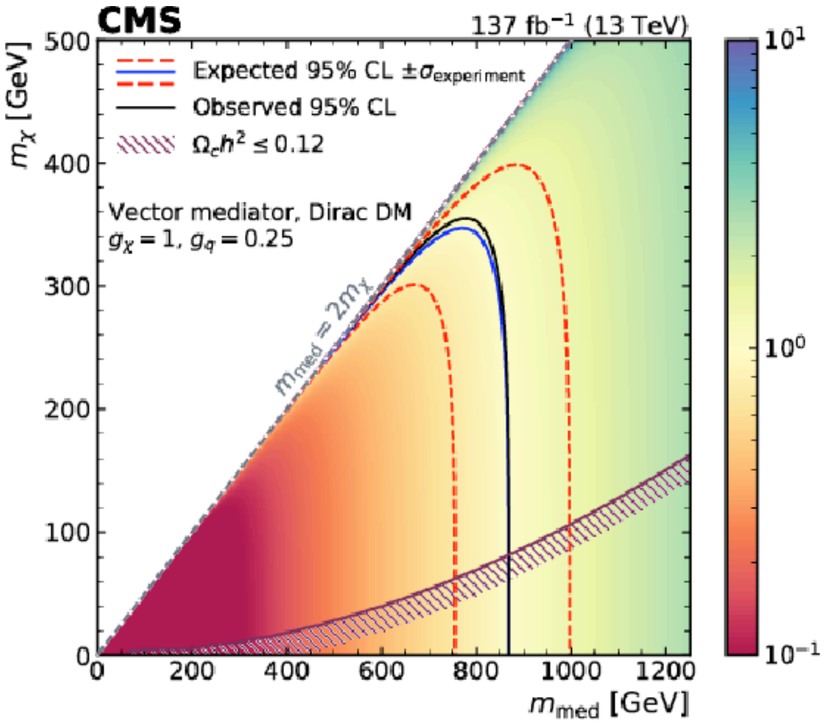
The 95% CL expected exclusion limits

mono-Z(ll) Search



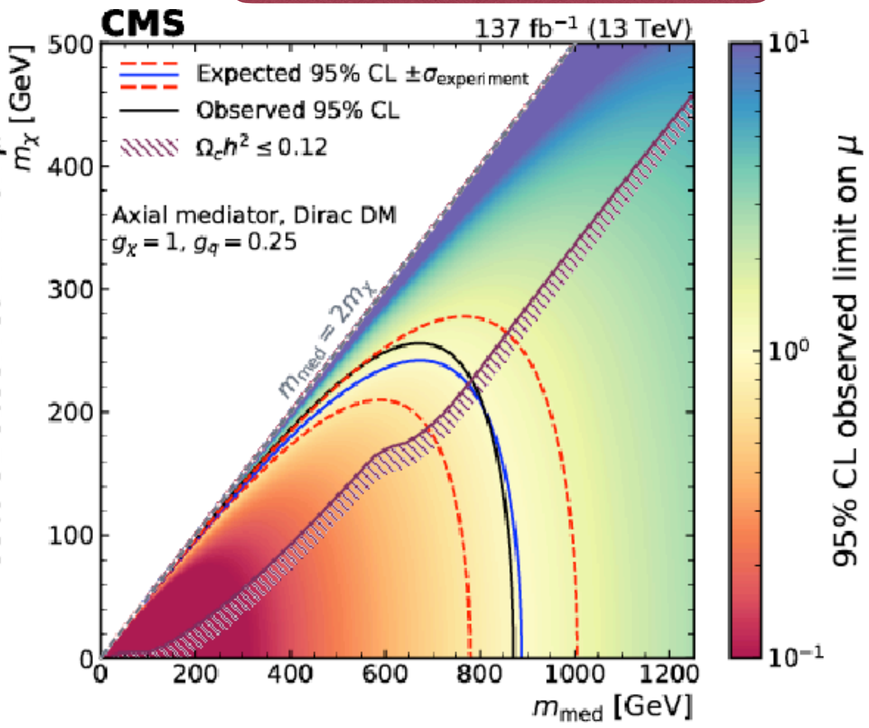
Simplified model interpretation

Vector mediator



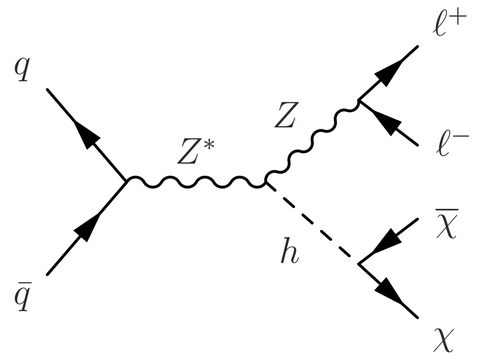
limit allowed for $m_{med} > 870$ GeV

Axial vector mediator



limit allowed for $m_{med} > 800$ GeV

Invisible Higgs boson interpretation



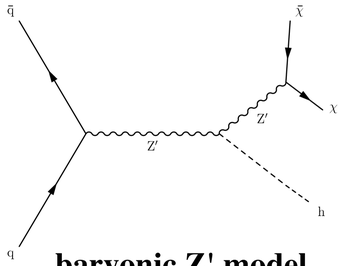
BR(H→ inv) < 29 % (25% exp)

mono-Higgs

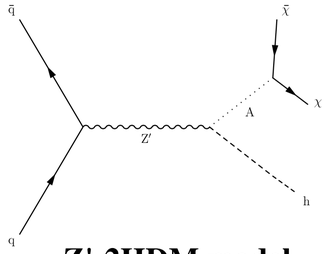
Search performance in five Higgs boson decay channels:
- h - > bb, h -> yy, h -> tau tau, h-> WW, h->ZZ

Two models for combined result interpretation.
- Z'-2HDM, baryonic Z' model

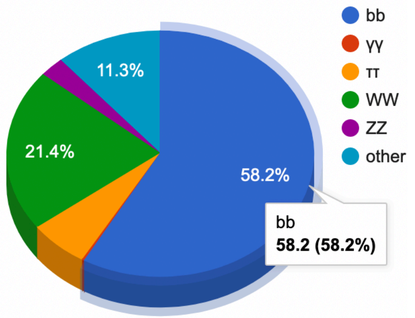
2HDM+a for h -> bb only

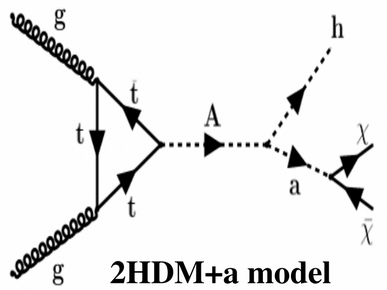


baryonic Z' model.

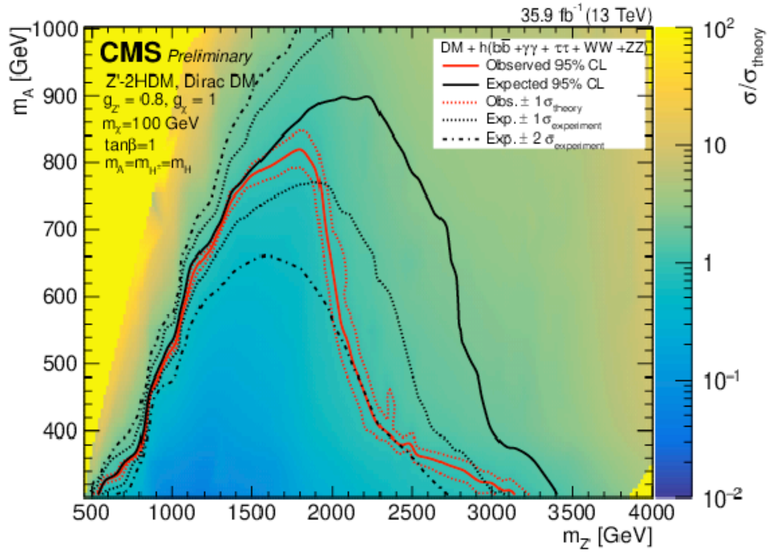


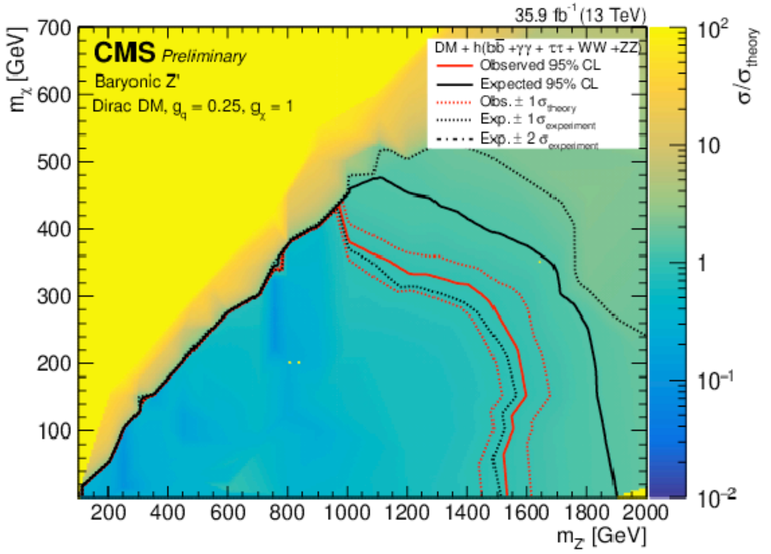
Z'-2HDM model

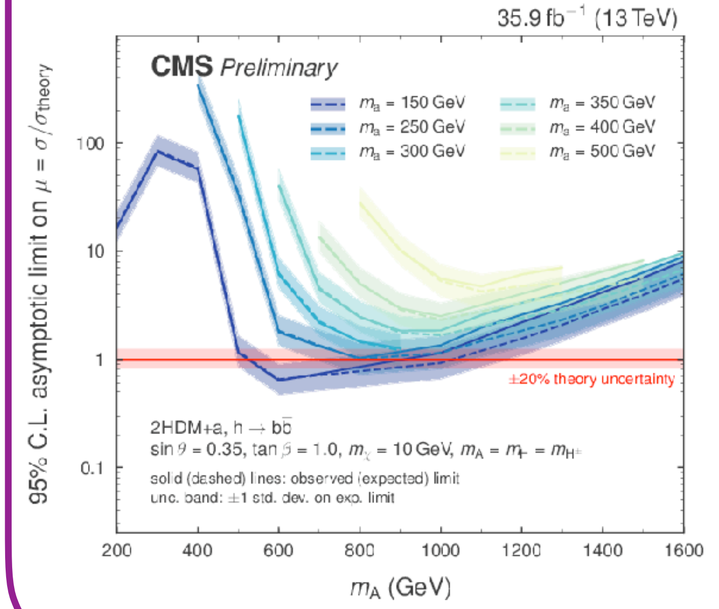




2HDM+a model

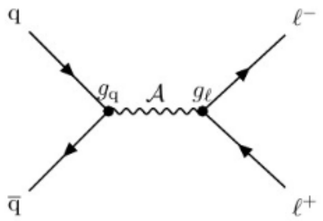


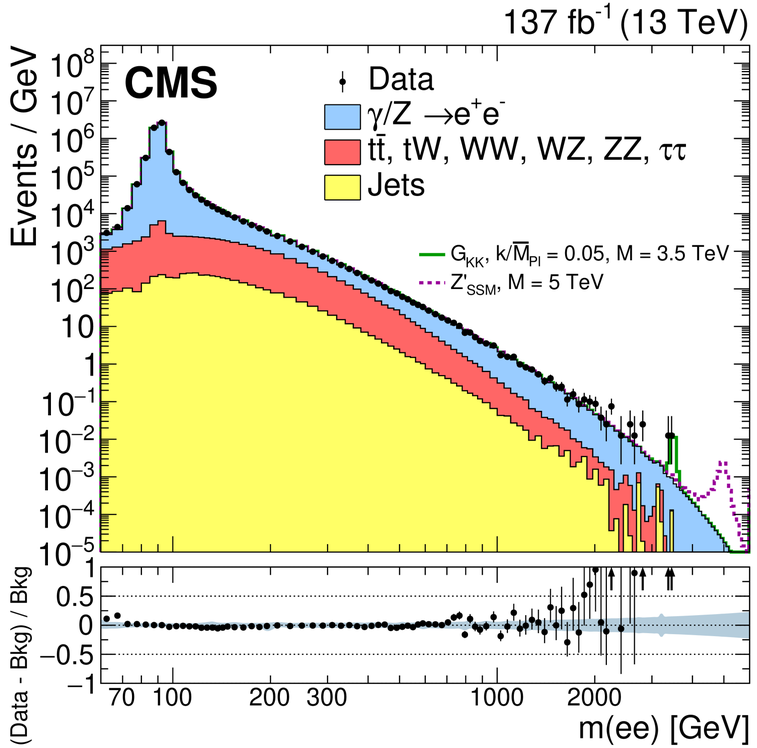


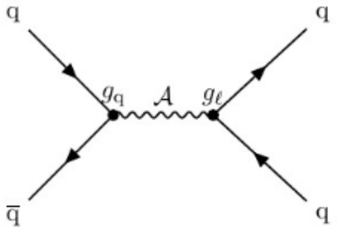


Resonance search

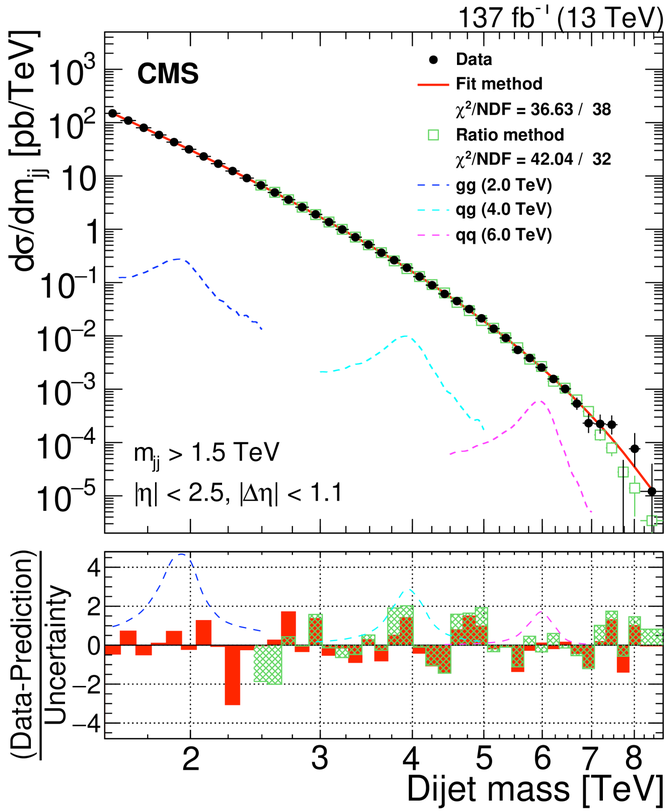
Final State: dilepton







Final State: dijet

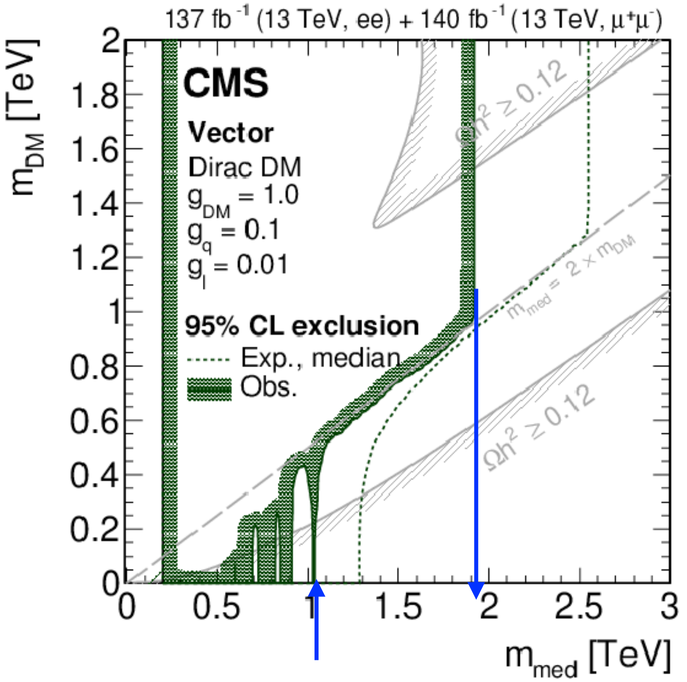


No peak is observed with respect to the SM background expectations.

Resonance search

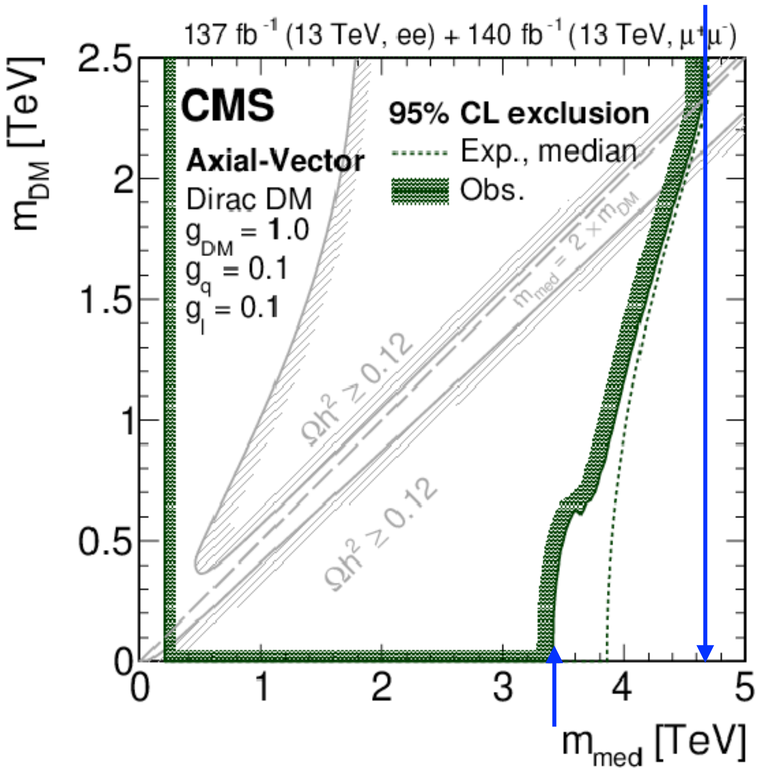
Dilepton final sate

Vector mediator



- m_{med} < 1.92 TeV excluded
- For m_{DM} = 0, 1.04 TeV excluded

Axial vector mediator

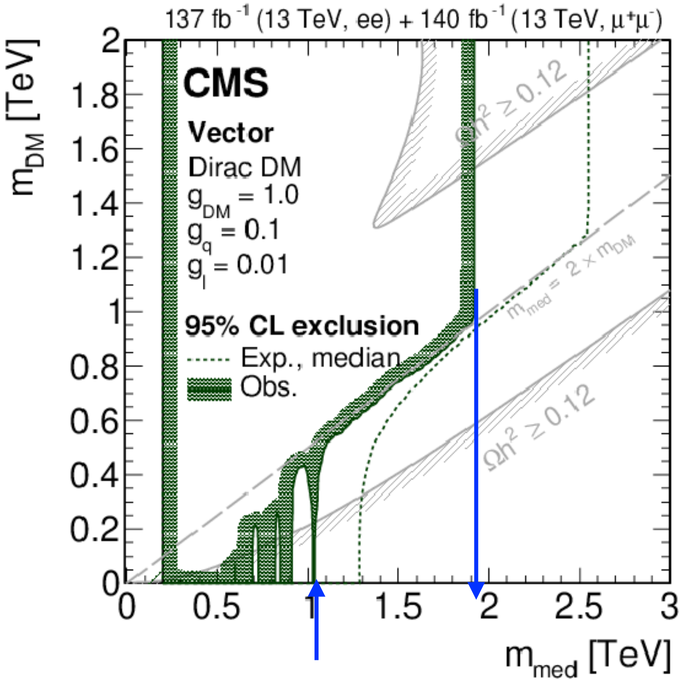


- m_{med} < 4.64 TeV excluded
- For m_{DM} = 0, 3.41 TeV excluded

Resonance search

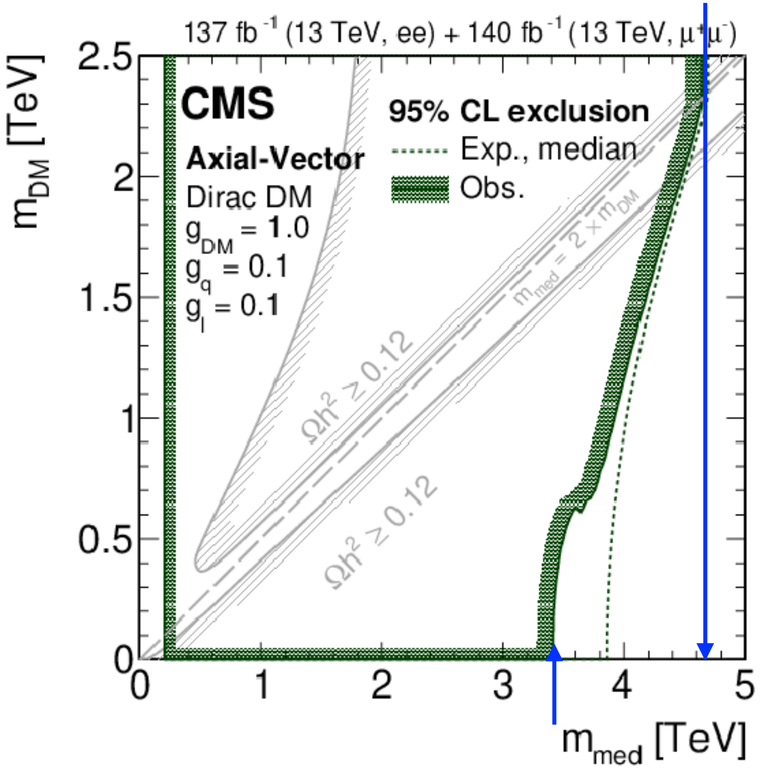
Dilepton final sate

Vector mediator



- m_{med} < 1.92 TeV excluded
- For m_{DM} = 0, 1.04 TeV excluded

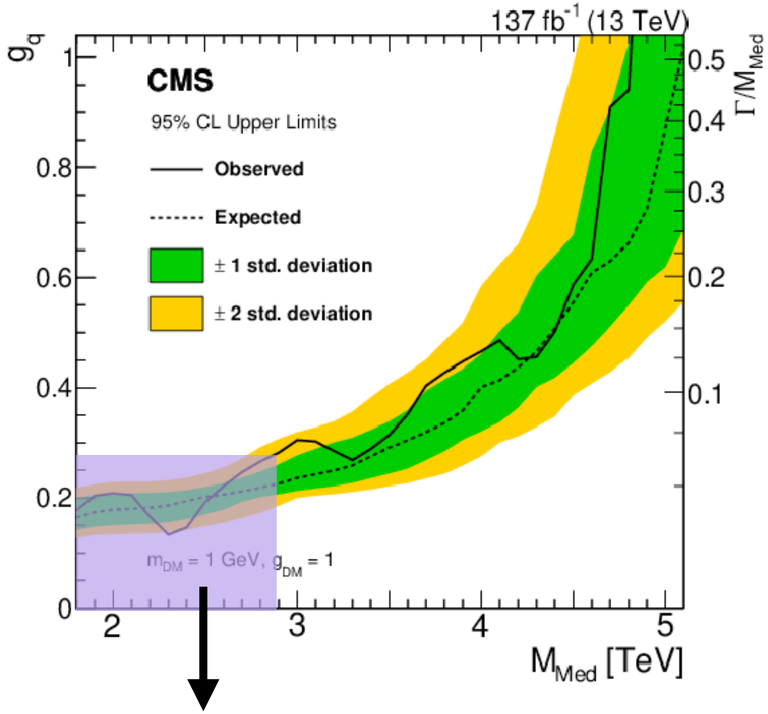
Axial vector mediator



- m_{med} < 4.64 TeV excluded
- For m_{DM} = 0, 3.41 TeV excluded

Dijet final sate

Vector mediator



Excluded upto 2.9 TeV, for gq = 0.25

Summary

- A brief summary of very exciting dark matter searches at CMS is presented.
- Full list of results are available here:
  - **Public results**
- No excess observed in any of the analysis.
- More results are coming soon with full run2

Thanks

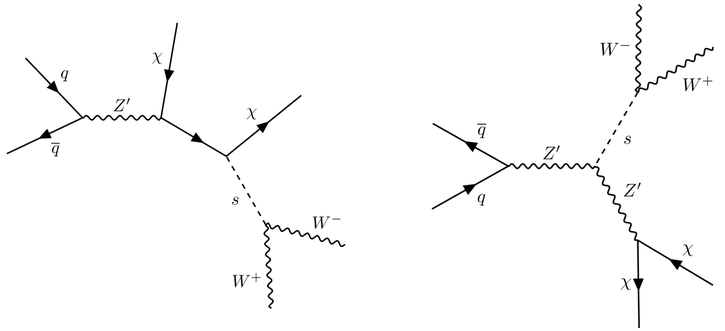
Dark Higgs

- **Dark Higgs:**
  - Higgs boson in Dark sector, responsible for generating the mass of DM.
- **Signature :**
  - Dark Higgs + missing energy
  - Dark Higgs (s) ->WW), WW (dileptonic decay
- **Basic selections:**
  - 160 GeV < m_s < 400 GeV
  - 195 GeV < m_z < 2500 GeV
- **Backgrounds:**
  - WW, Top, Drell–Yan

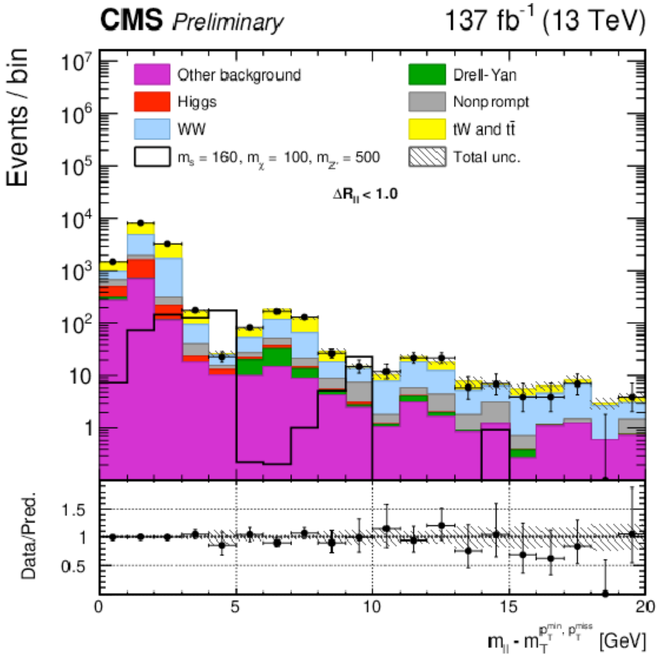
- **Observable:**
  - Transverse mass of the trailing lepton plus p_T^{miss} system

$$m_{\mathrm{T}}^{\ell\,\mathrm{min},p_{\mathrm{T}}^{\mathrm{miss}}} = \sqrt{2p_{\mathrm{T}}^{\ell\,\mathrm{min}}p_{\mathrm{T}}^{\mathrm{miss}}\left[1-\cos\Delta\phi(\vec{p}_{\mathrm{T}}^{\ell\,\mathrm{min}},\vec{p}_{\mathrm{T}}^{\mathrm{miss}})\right]}$$

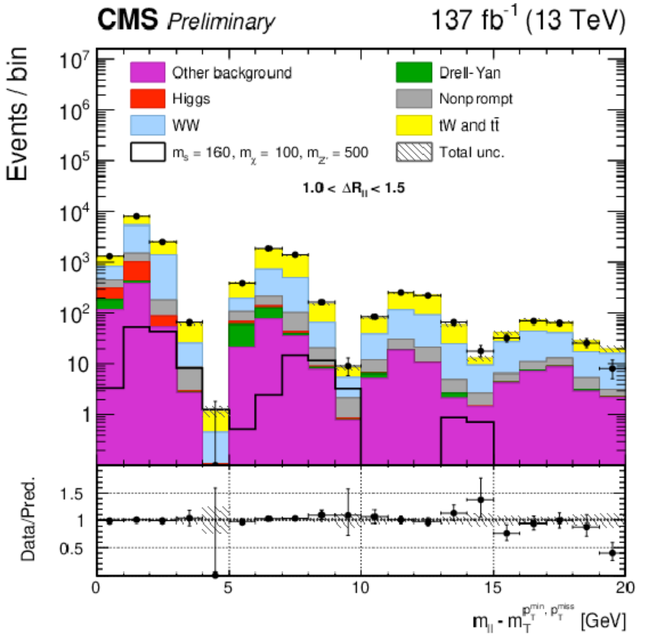
- **Final fit:**
  - 2D profiled fit to the invariant mass of the dilepton system, m_{ll} and the $m_T^{lmin,\ pTmiss}$



Representative Feynman diagrams for the dark Higgs simplified model



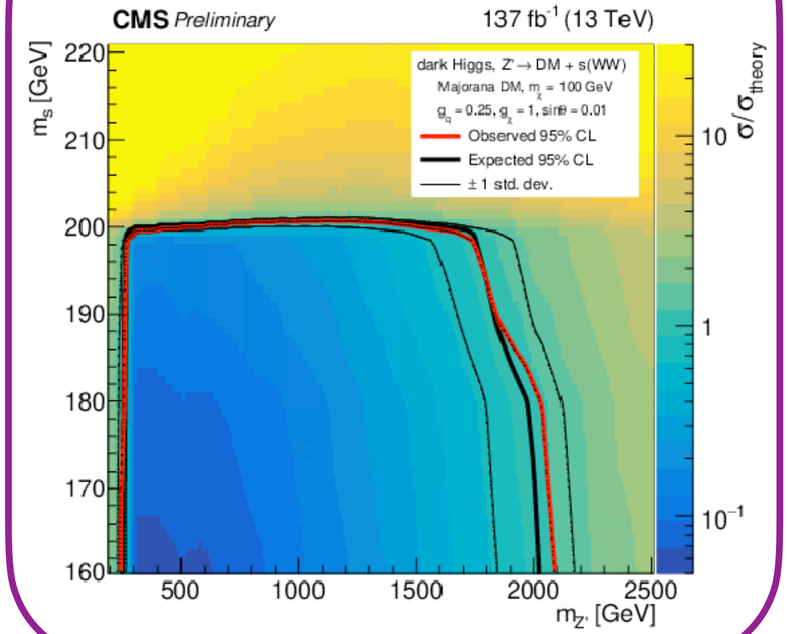
The unrolled $m_{\ell\ell}$-$m_{\mathrm{T}}^{\ell\,\mathrm{min},p_{\mathrm{T}}^{\mathrm{miss}}}$ post-fit distributions



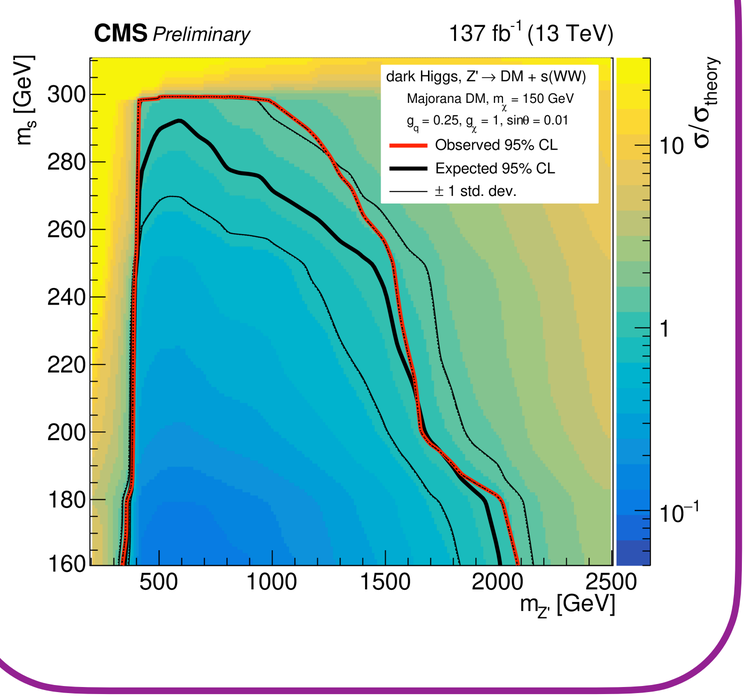
Dark Higgs

- No significant deviation from the standard model prediction is observed.
- Upper limits at 95% confidence level on the production cross section of dark matter are set in the dark Higgs model parameters

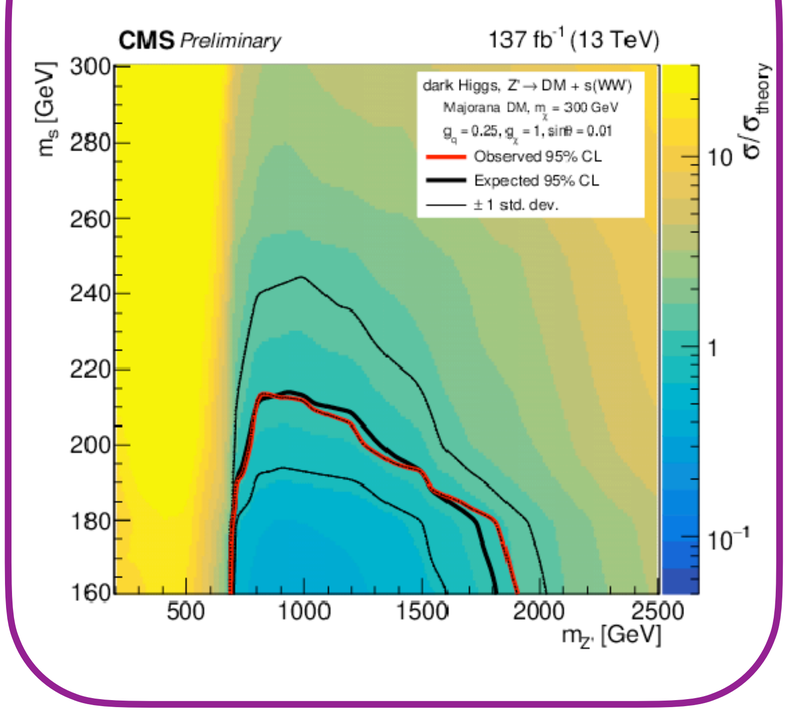
m_χ = 100 GeV



m_χ = 150 GeV



m_χ = 300 GeV



The most stringent limit is set for a m_χ = 150 GeV, m_s < 300 GeV and 480 < m_Z < 1200 GeV excluded